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Optimization of process parameters during Friction Stir Welding of dissimilar aluminium alloys using Grey relational analysis

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ABSTRACT

In this work an attempt has been made to optimize the process parameters during Friction stir welding of two different aluminium alloys. An L9 orthogonal array has been designed to fabricate the joints. The major input parameters considered are rotational speed, Welding speed and axial force. The performance measures include hardness and tensile strength. Multi parameter optimization is been done using grey relational analysis. The results indicate that welding speed has maximum influence with 61.68% followed by axial force and rotational speed with 26.64 and 11.68%. On optimization it is found that rotational speed of 800mm/min, Axial force of 14.5 KN and welding speed of 45 mm/min is the best parameter setting for the welding of aluminium alloys.

KEY WORDS: Aluminium Alloys, Friction stir welding, Grey relational analysis, Rotational speed, Welding speed, axial force

1. INTRODUCTION

The joining of two dissimilar alloys is not possible in case of conventional welding. Such welding of dissimilar alloys can be done with help of friction stir welding, the properties of the weld being dependent on various parameters such as rotational speed, welding speed, axial force, Pin profile etc. Mechanical properties of FSW and the influence of the process parameters have been widely investigated.

2. EXPERIMENTAL PROCEDURE

Tool Design: The tool design is one of the important factors of friction stir welding. It has been previously determined that the square pin profile produced efficient welds. The tool is made of H13 tool steel. The tool used in this experiment has a cylindrical pin. It is designed such that the length of the pin is 1mm less than the thickness of the plate. The cylindrical work piece is then machined using the lathe. The work piece is then hardened by annealing process. The annealing temperature of H13 tool steel is 850-9000C. The tool is placed in the furnace and heated to 8500C and kept in that temperature for 2 hours. The induction furnace is switched off and the tool is allowed to cool in the furnace itself. The tool is retrieved the next day. The finished tool is shown in figure 1.

Friction Stir welding of Aluminum alloys: The plats are marked for identification. The plates are then clamped onto the fixture by the nuts as shown in figure 2. It is ensured that they do not move during the welding. Care is taken to keep the same alloy on the advancing side or the retreading side respectively. In this experiment the AA5052 is placed in the advancing side and AA7075 was placed in the retrieving side. The machine (figure 3) has an in-built console to control rotational speed, transverse speed and axial force. The spindle speed is controlled by a 5 HP motor. The transverse speed is controlled by a hydraulic system along with a cascaded bed. The axial force is also adjusted by adjusting the pressure on the hydraulic system.

Figure.1. showing the tool used in friction stir welding of aluminium alloys

Figure.2. Showing clamping of plates during FSW of aluminium alloy

Figure.3. showing Friction stir welding machine

The tool pin is brought near the interface and then plunged into the plates until the shoulder is also a little sunk into the cylinder. And the transverse feed is switched on. The same procedure is done for all the plates adjusting the parameters accordingly every time. The welded samples are cooled and marked for identification. After the welding is done various mechanical tests such as hardness and tensile test have been carried out on the samples. The various input parameters and their levels are shown in table below.

Table.1. Process parameters and their levels

Variable	Low	Medium	High
Rotational Speed	800	1000	1200
Welding speed	30	45	60
Axial force	12.5	14.5	17.5

Table.2. L_9 Orthogonal Array based on taguchi design

Rotational Speed	Welding speed	Axial Force
800	30	12.5
800	45	14.5
800	60	17.5
1000	30	14.5
1000	45	17.5
1000	60	12.5
1200	30	17.5
1200	45	12.5
1200	60	14.5

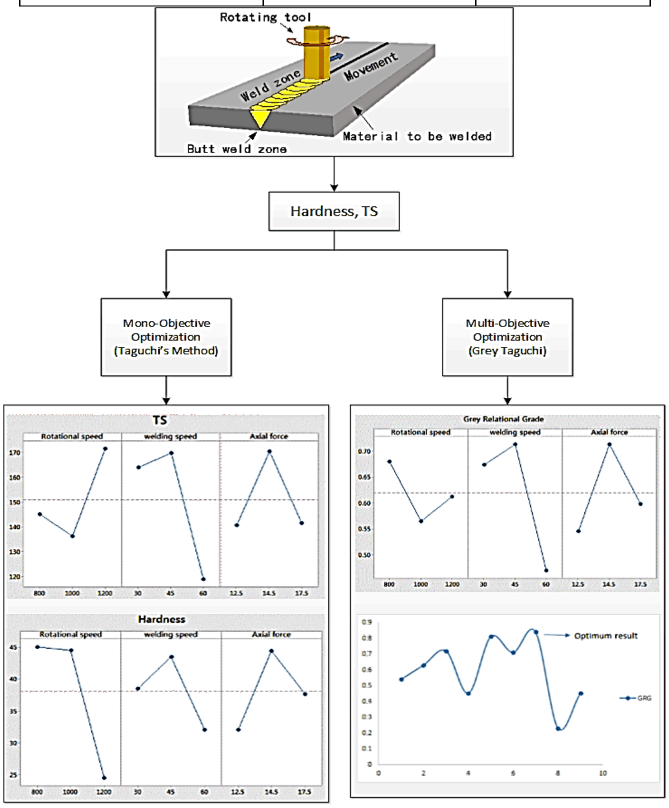

Figure.4. showing Flowchart of Optimization of process parameters of FSW

Taguchi Methodology: Taguchi methodology is mainly used to reduce the number of experiments by specially constructed tables called orthogonal arrays. In this work L9 array is used to conduct the experiments. This consists of three parameters and three levels which are shown in Table 1. The design matrix obtained is shown in Table 2.

Grey Relational Analysis: Mostly Taguchi method is used for optimization of single parameter (i.e Mono-objective optimization). By combining taguchi with grey relational analysis optimization based on multiple parameters can be done easily and effectively. The grey relational analysis involves calculation of grey relational coefficient for each parameter and average of all grey relational coefficients is taken as grey relational grade which is used as response for the L9 orthogonal array.

Normalization of data: The experimental response data are to be normalized in the range of 0 and 1. This data processing is necessary since data range in one output parameter may be different from other parameters and also the scatter range is also high. In this work the tensile strength and hardness are the measured responses in terms of rotational speed, welding speed and axial force.

For the "larger the better" responses the normalization can be done using the equation (1).

$$x_i^* = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad \text{--------------------------------(1)}$$

For the "Smaller the better" responses the normalization can be done using the equation (2)

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \quad \text{----------------------------(2)}$$

Next the derivation sequence is calculated using Equation (3)

$$\Delta_{Oi} = \left| x_o^*(k) - x_i^*(k) \right| \text{ ----------------------------------(3)}$$

The values of S/N ratios and normalized S/N ratios as well as the deviation sequence for all the parameters is shown in table 3

Computation of Grey relational coefficient and Grey Relational Grade: Grey relational coefficient for each response can be calculated from the equation (4)

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta.\Delta_{\max}}{\Delta_{0i}(k) + \zeta.\Delta_{\max}} \text{ -----------------------------(4)}$$

Where ζ is distinguishing coefficient and $\Delta_{oi}(k)$ is called deviation sequence.

After obtaining the grey relational coefficient the grey relational grade is obtained by averaging the grey relational coefficient of all the responses in the individual experimental run. If all the parameters are given equal preference then ζ is taken as 0.5.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

3. RESULTS AND DISCUSSION

ANOVA Analysis for Hardness: The effect of input parameters on the hardness is shown in figure 5. The performace is said to be optimized when the hardness of the joint is high. Hence from the above figure it is infered that the most optimized condition for better performance is $A_1B_2C_2$.

The effect of input parameters on the Tensile strength is shown in figure 6. The performace is said to be optimized when the tensile strength of the joint is high. Hence from the above figure it is infered that the most optimized condition for better performance is $A_3B_2C_2$.

Figure.5.Shows the effect of input parameters on Hardness

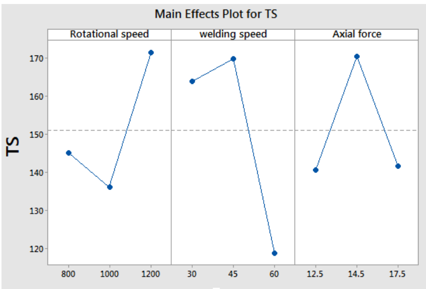

Figure.6.Effect of input parameters on Tensile strength

Table.3. ANOVA table for Tensile strength.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Rotational speed	2	2027.9	23.08%	2027.9	1014	5.4	0.156
welding speed	2	4664.6	53.10%	4664.6	2332.3	12.41	0.075
Axial force	2	1716.3	19.54%	1716.3	858.1	4.57	0.18
Error	2	375.9	4.28%	375.9	187.9		
Total	8	8784.6	100.00%				

Table.4.ANOVA table for Hardness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Rotational speed	2	822.8	44.66%	822.8	411.41	1.39	0.419
welding speed	2	228.9	12.42%	228.9	114.46	0.33	0.75
Axial force	2	593.4	32.20%	593.4	296.68	0.39	0.722
Error	2	197.5	10.72%	197.5	98.75		
Total	8	1842.6	100.00%				

Multi objective optimization: Multi objective optimization is done by applying grey relational analysis following the steps mentioned below. The Grey relational coefficient and Grey relational grade for each run is shown in the table 5.

Table.5. Experimental results of FSW of aluminium alloy

Experiment No	Hardness	Tensile strength
Reference sequence	1	1
1	35.33	140.11
2	68.33	191.63
3	31.667	103.58
4	44.333	168.57
5	45.333	138.03
6	44.000	102.02
7	36.000	183.22
8	17.000	180.20
9	20.667	151.24

Table.6.Experimental vs predicted result for Hardness

Experiment No	Experimental	predicted
1	35.33	39.629
2	68.33	56.96
3	31.66	38.741
4	44.33	51.40
5	45.33	49.62
6	44.00	32.629
7	36.00	24.629
8	17.00	24.07
9	20.66	24.96

Table 6 & Fig 7 Showing Experimental vs predicted result for Hardness. The predicted value is very closer to the experimental value. The percentage of error value is 0.010%.

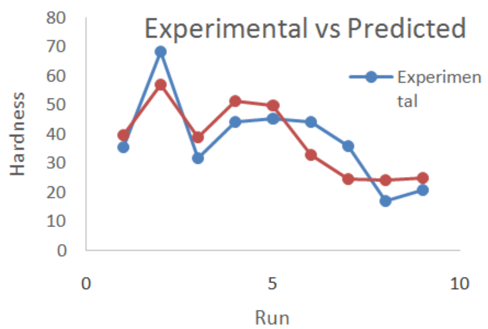

Figure.7. Experimental vs predicted result for Hardness

Table.7.Experimental vs predicted result for Tension strength

Experiment No	Experimental	predicted
1	140.12	147.95
2	191.63	183.63
3	103.58	103.75
4	168.57	168.74
5	138.03	145.86
6	102.02	94.02
7	183.22	175.22
8	180.20	180.37
9	151.24	159.07

Table 7 & Fig 8 Showing Experimental vs predicted result for Tension strength. The predicted value is very closer to the experimental value. The percentage of error value is 0.00.

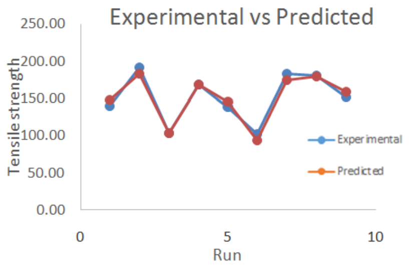

Figure.8.Experimental vs predicted result for Tension strength

Table.8. Experimental vs predicted result for GRG

Experiment No	Experimental	predicted
1	0.582	0.662
2	1.000	0.869
3	0.458	0.509
4	0.664	0.715
5	0.559	0.639
6	0.473	0.342
7	0.778	0.647
8	0.583	0.634
9	0.478	0.558

Table 8 & Fig 9 Showing Experimental vs predicted result for Grey Relational Grade. The predicted value is closer to the experimental value. The percentage of error value is 0.00%

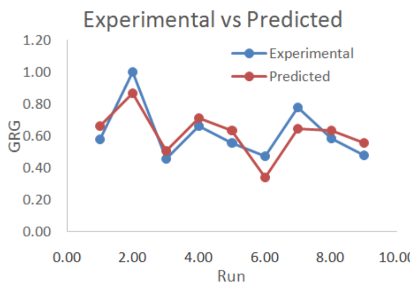

Figure.9.Experimental vs predicted result for GRG

Table.9.Grey relational coefficients and Grey relational grade

Experiment No	Grey relational Coefficient		Grey Relational Grade
	Hardness	Tensile strength	
1	0.5133	0.501	0.582
2	1.0000	1.000	1.000
3	0.4748	0.338	0.458
4	0.6165	0.711	0.664
5	0.6291	0.489	0.559
6	0.6124	0.333	0.473
7	0.6810	0.875	0.778
8	0.3330	0.836	0.583
9	0.3840	0.571	0.478

The effect of process parameter on Grey Relational Grade is shown in fig 10. From the below figure it is observed that the rotational speed of 800, welding speed of 45 and an axial force of 14.5 KN is the most optimized condition for higher Grey Relational Grade and better mechanical properties.

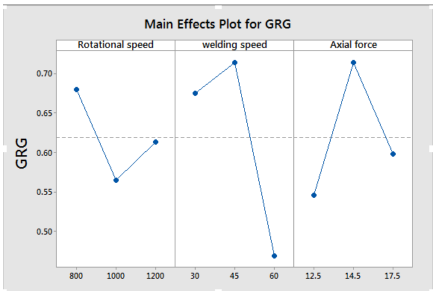

Figure.10. showing Main effects of Process variables on Grey relational grade

Since the design is orthogonal it is possible to separate out the effect of each parameter on the grey relational grade at different levels. The mechanical performances will be higher when the grey relational grade is higher. Hence higher grey relational grade is desirable for optimum performance. Hence the optimum settings for hardness and tensile strength are (A1B2C2) as shown in response table. (Table 10).

Table.10.Showing response levels for Grey Relational Grade

Level	**1**	**2**	**3**	**Delta**	Rank
Rotational speed	-3.828	-5.039	-4.426	1.211	3
welding speed	-3.48	-3.246	-6.567	3.322	1
Axial force	-5.299	-3.324	-4.671	1.975	2

The ANOVA table (Table 11) for Grey Relational Grade shows that the welding speed has highest influence on Grey Relational Grade (42.03%) followed by rotational speed (31.82%) and axial force (18.03%).

Table.11. ANOVA for Grey Relational Grade

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Rotational speed	2	0.07825	31.82%	0.07825	0.039126	0.25	0.797
welding speed	2	0.10336	42.03%	0.10336	0.051679	1.32	0.431
Axial force	2	0.04434	18.03%	0.04434	0.022172	0.57	0.638
Error	2	0.01995	8.11%	0.01995	0.009976		
Total	8	0.24591	100.00%				

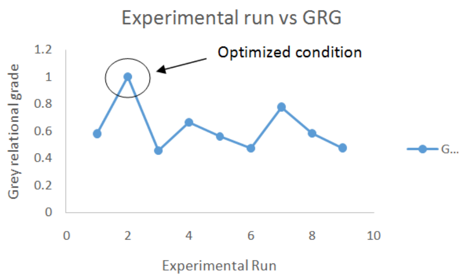

Figure.11.Optimized condition for Grey relational Grade

4. CONCLUSIONS

The relationships between process parameters for FS welding of AA5052-7075 aluminum alloy have been established using Taguchi method, which were checked for their adequacy using ANOVA test and found to be satisfactory. Interaction plots and contour plots were drawn to study the effect of FSW parameters on the tensile strength of friction stir welded joints of AA5052-7075 aluminium alloy. Friction stir welding is an efficient process and is especially indispensable because it can be used to weld certain alloys that are “unweldable” using conventional welding methods. The mechanical properties of the weld are good and desirable. The optimum values of the parameters were found and can be used for further study.

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